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Forest Service

**Technology &
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Program**

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2300 Recreation
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5300 Law Enforcement
5400 Lands
6700 Safety & Health
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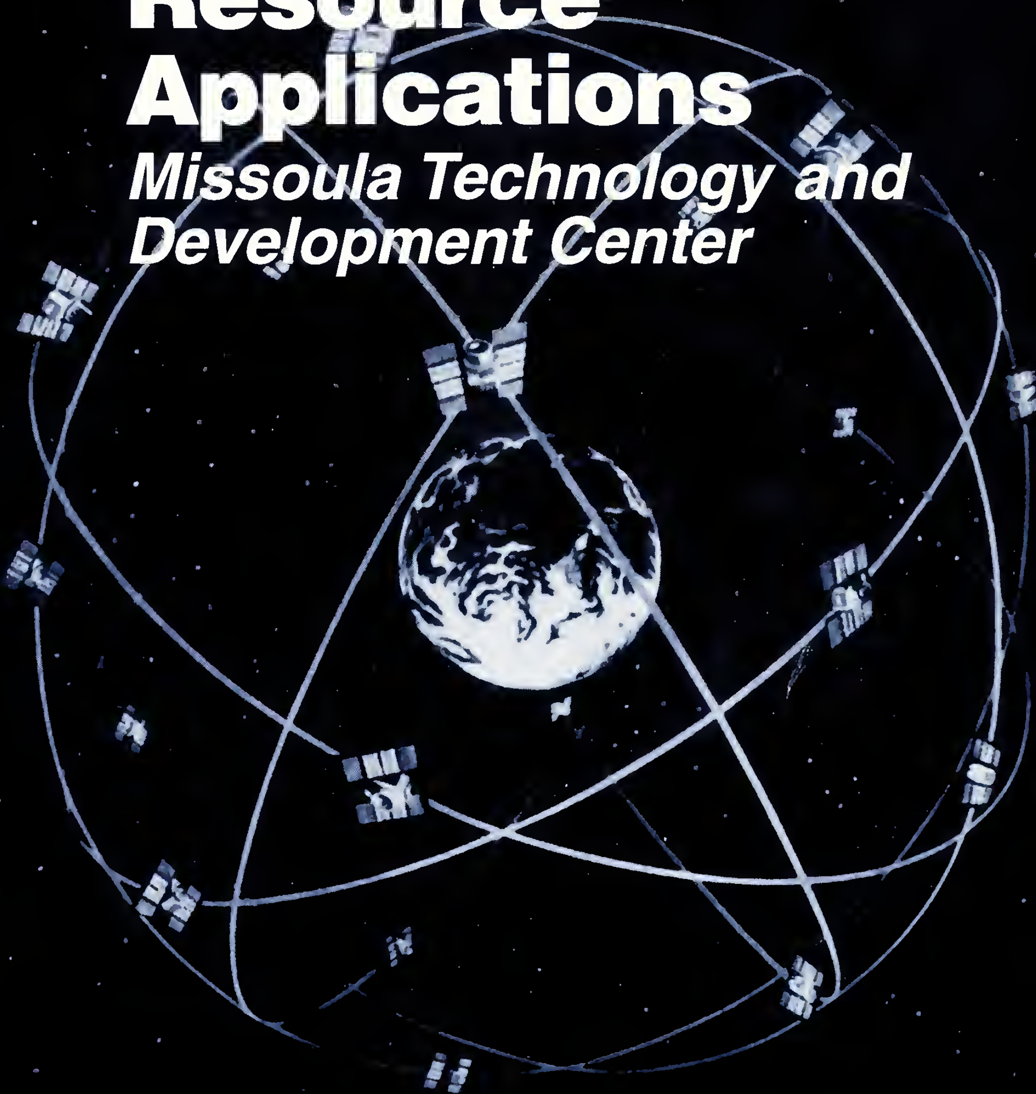
Two Decades of Development and Evaluation of GPS Technology for Natural Resource Applications

Missoula Technology and Development Center



Author's Notes

The idea for this publication came from requests to summarize the large number of Missoula Technology and Development Center documents relating to GPS technologies. The use of GPS technology and related applications has been one of the most active areas of development at MTDC over the past 15 years. The history of MTDC's development work is a history of the applications of GPS technology in natural resource management. As applications of this technology continue to appear, MTDC plans to maintain a strong technical role in developing, directing, and evaluating these applications to meet Forest Service needs.

Acknowledgments

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- **Timber Management**
- **Engineering**
- **Forest Health Protection**
- **Fire and Aviation Management**
- **Law Enforcement**
- **Research**
- **Lands and Minerals**
- **Wildlife**
- **Recreation**
- **International Forestry**

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Two Decades of Development and Evaluation of GPS Technology for Natural Resource Applications

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USDA Forest Service
Technology and Development Program
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Table of Contents

Introduction

Global Positioning System (GPS)-based positioning and navigation has had a great impact on resource management operations. The Department of Defense first declared the system fully operational in 1995. Since then, GPS has been accepted as a primary tool in many areas of Forest Service activity.

GPS receivers are used to pinpoint Forest Inventory and Analysis plots, nesting tree locations, and resources along forest roads. GPS technology has taken the place of ground markers to delineate spray block boundaries in pest suppression and to plot the location of new trails for recreation managers. Fire and Aviation Management uses GPS for aircraft guidance and to position camps and equipment.

This summary document describes how GPS works, and records the history of its use within the Forest Service. It recounts the Missoula Technology and Development Center's early involvement with GPS and the many contributions the Center has made to the acceptance of GPS in all areas of resource management.

GPS History

In 1957, scientists at the Johns Hopkins Applied Research Laboratory were tracking the newly launched Russian Sputnik and determining its orbit by measuring the Doppler shift in frequency received from the satellite. While doing this, they reasoned that if an unknown orbit could be determined from a known point on earth, then the reverse should also be possible. This observation led to the Navy's TRANSIT satellite navigation program designed for the exclusive use of Polaris ballistic missile submarines. The TRANSIT constellation was in place by the end of 1962, and demonstrated the 24-hour, all-weather capability of a satellite navigation system. In 1967, a limited number of nonmilitary users were given access to TRANSIT. The Navy decommissioned this system in 1996.

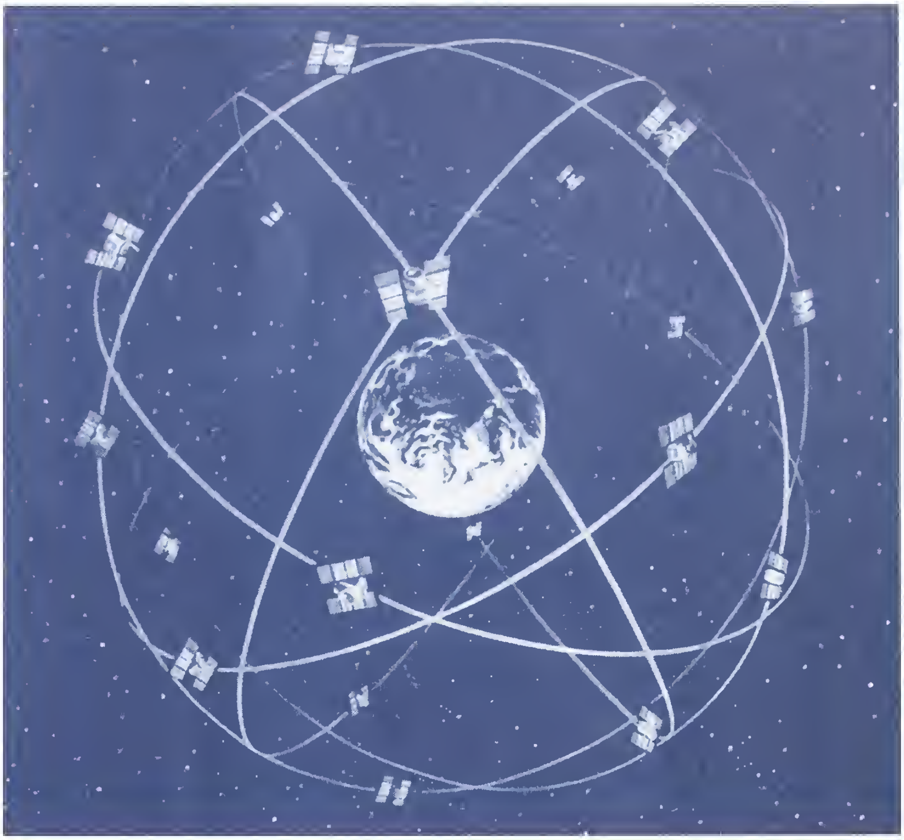


Figure 1—The operational GPS satellite constellation consists of 24 NAVSTAR satellites arranged in six 55° planes around the Earth so that a minimum of four satellites would always be in view above the horizon.

The Global Positioning System

The Department of Defense (DOD) launched the first Global Positioning System satellite in 1978. GPS evolved from the earlier technology of TRANSIT but was designed to be available to all branches of the military. It took 17 years from launch of the first test satellite to a fully operational satellite constellation, control segment, and user equipment segment. DOD declared GPS fully operational in 1995.

The initial concept included 24 NAVSTAR satellites in the Global Positioning System constellation, (Figure 1) with 21 operational and 3 as active spares. The satellites are arranged in six orbital planes at an inclination angle of 55° with four satellites in each plane. The orbit altitude is 20,200 km. The orbit period for each satellite is about 12 hours. This arrangement ensures that a minimum of four satellites will always be in view above the horizon at any time from any point on earth.

The signal broadcast from each satellite (Figure 2) identifies the satellite, its status, its location and time. This precise time is used by the ground-based GPS receiver to calculate the distance to the satellite. The receiver determines the time of broadcast and the position of the satellite at the time of broadcast based on the satellite identification and the almanac. The difference between the broadcast time and reception time is used to determine the distance to a given satellite. If distances can be calculated to a minimum of four satellites, a position in three dimensions can be determined. If more satellite signals are available, more distances can be calculated and the position can be optimized.

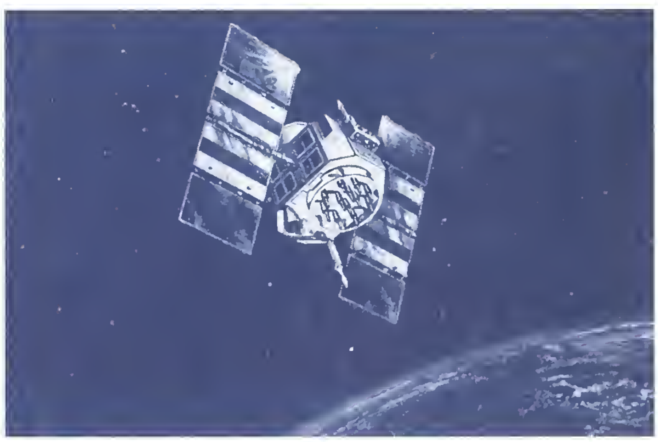
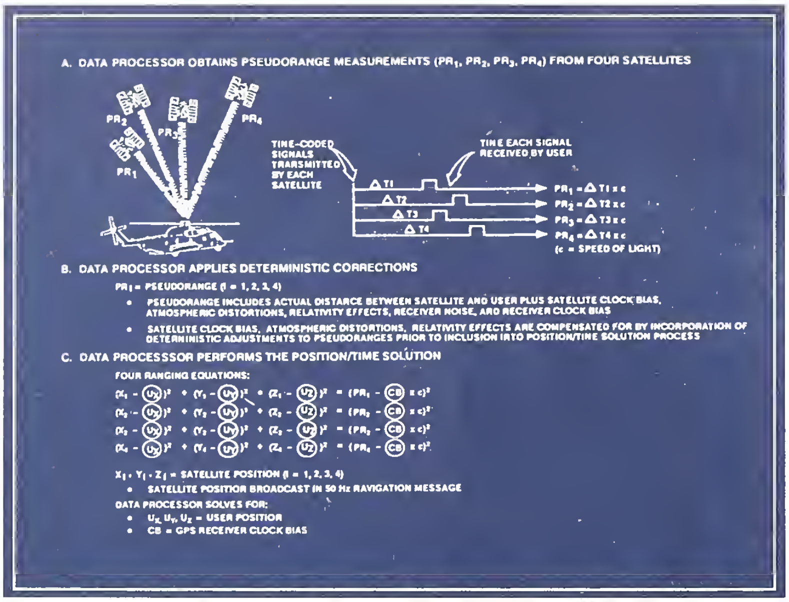
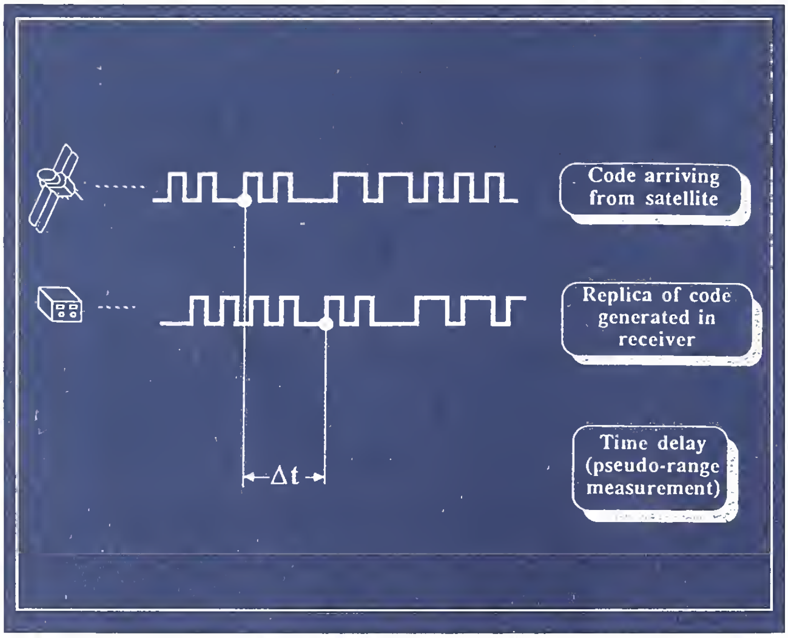


Figure 2—From the launch of the first satellite in 1978, 17 years passed before the GPS constellation was declared fully operational in 1995.





To calculate its position, the GPS receiver determines the time it takes the satellite signal to travel from the satellite to the receiver. The receiver must receive at least four satellite signals simultaneously to resolve its position. The receiver compares the received signal to that of a replica signal generated in the receiver. The time shift necessary to synchronize these two signals within the receiver represents the transit time for the received signal. This is done simultaneously for each satellite signal received. The pseudorange to each satellite is determined by multiplying the transit time of each satellite signal by the speed of light. The satellites transmit their positions in Cartesian coordinates (x, y, and z) with the center of mass of the Earth at 0,0,0. With the satellite position and the pseudorange to the four satellites known, four ranging equations can be written and solved for the receiver clock bias and the receiver position.

The signal is broadcast on two frequencies: the primary L1 at 1575 MHz, and a second L2 at 1227 MHz. Most civilian users, are afforded access only to the L1 Coarse Acquisition code (C/A) modulated at a chipping rate of 1.023 MHz. This signal is unencrypted. However, DOD purposely degrades its accuracy. The Department of Defense guarantees that C/A positional accuracy will be within 300 meters 99.9% of the time and within 100 meters or less 95% of the time. This is called the Standard Positioning Service (SPS). Civilian users have asked for access to the L2 signal for ionospheric calibration purposes.

The Precise Positioning Service (PPS) signal is intended for military use only. In 1995, the DOD began allowing some civilian government agencies access to PPS receivers. The PPS signal is broadcast on both the L1 and L2 frequencies. The PPS precision code is a long code modulated at a chipping rate of 10.23 MHz, 10 times faster than the C/A code (1.023 MHz). When this P code is encrypted, as it is under current DOD policy, it is referred to as the Y code. Because of the Y code's higher chipping rate, it is inherently more precise than the C/A code. Military P(Y) code receivers are guaranteed 16 meters maximum horizontal error.

Selective Availability

Because of security concerns, DOD denies nonmilitary users the highest accuracy of the GPS system by purposely degrading the C/A code. This signal degradation is called Selective Availability (SA). SA is achieved by introducing a fluctuating timing error and satellite location error into the signal broadcast by each satellite. The L1 frequency contains two codes, the Precision (P) code and the Coarse/Acquisition (C/A) code. The L2 carrier contains only the P(Y) code. Dual-frequency military receivers can access the P(Y) codes on both frequencies, while civilian receivers are limited to the L1 C/A codes.

DOD has turned off SA only once. During the Gulf War, the Armed Forces were short of military GPS receivers and made an emergency purchase of off-the-shelf commercial units. DOD had to turn off SA to allow field units with these receivers to acquire the accuracy they needed. Selective Availability has been on continuously since then.

Differential GPS

The civilian GPS community developed Differential GPS (DGPS) to overcome the errors induced by SA. DGPS involves siting a reference (or base) station at a surveyed position. Computer software compares the surveyed position to the GPS-derived position and computes corrections (vectors) that can then be applied to other receivers. This correction factor can be archived for future use or transmitted to nearby GPS receivers for real-time correction. It can also be incorporated into GPS data at a later date (postprocessing). However, navigation and guidance functions such as those used in aerial pesticide application require real-time correction. Recent developments in broadcasting differential corrections include ground-based beacons as well as commercial satellites that broadcast corrections over a wide area. Many DGPS systems are accurate to less than a meter. Survey-grade accuracy of a few centimeters is possible using differential corrections and the appropriate equipment.

Precise Positioning Service P(Y) Code

The DOD has authorized some civilian governmental agencies to purchase the military Precise Positioning Service (PPS) receivers capable of operating with the P(Y) code. The Forest Service began buying these receivers in February 1995. The Forest Service was allowed to purchase the Trimble Centurion and the Rockwell Precision Lightweight GPS Receiver (PLGR). Both are hand-held units containing a code module that must be "rekeyed" at least once a year. While they are not classified, they are accountable items of equipment because of the security module they contain. Program coordinators must implement special handling procedures with the P(Y) code receivers.

Surveying

The first GPS receivers in the Forest Service were used for surveying in the mid-1980's. A company provided the receivers, processing software, and technical knowledge for the Forest Service. These receivers cost around $75,000 each. A minimum of three receivers were required to bring the geodetic control from a known location into the desired area.

These first survey-grade GPS receivers were large, heavy, and power hungry (Figure 3). A 12-volt automotive battery would only operate the unit for 3 to 4 hours. It took 45 to 90 minutes to obtain accurate data at each station. This required considerable preparation as the satellite constellation in the early days included only four to five satellites, the minimum required for positioning. The data had to be collected simultaneously from all the satellites. All satellites were available only for $3^1/_2$ to $4^1/_2$ hours a day.

The Forest Service separated GPS activities into two functions: surveying and resource management. The two functions had different requirements. Survey-grade receivers have to track both the C/A code and the signal phase continuously. This requires a clear view of the sky 10° to 15° above the horizon to prevent losing the lock and to prevent cycle slip. This type of receiver does not work for resource-management activities where much of the work is under the forest canopy. Resource-management work required a receiver that tracked only C/A code and that could tolerate signal interruptions caused by the canopy.

The land surveyors in each Region were responsible for implementing survey-grade GPS technology. MTDC was given the responsibility for implementing GPS technology into resource management activities Servicewide.

Figure 3—The first GPS receivers were large, heavy, and power hungry.

GPS Documents Produced by MTDC

- *Global Positioning System Canopy Effects Study*, September 1989
- *Satellite Tracking of Log Rafts*, September 1992
- *Evaluating GPS Under Dense Tree Canopy*, April 1993
- *GPS Use Survey Results*, March 1994
- *GPS Use in Wildland Fire Management*, May 1994
- *Spray Block Marking*, September 1994
- *Trimble Centurion GPS Receivers*, February 1995
- *Military PLGR GPS Receiver*, June 1995
- *Philippine GPS Training*, November 1995
- *Indonesian GPS Training*, November 1995
- *Forest Health Through Silviculture—Proceedings of 1995 National Silviculture Workshop*, May 1995
- *DGPS in Aerial Spraying in Forestry: Demonstration and Testing*, September 1995
- *Differential GPS Aircraft Navigation, Resource Inventory, and Positioning Demonstration, Missoula, Montana—October 1995*, May 1996
- *Real-Time Global Positioning System (GPS) Evaluation*, July 1996
- *GPS Evaluation: West Coast Test Site*, September 1996
- *Harrisonburg Spray Aircraft Navigation Demonstration Test Plan*, December 1996
- *GPS Traverse Methods*, February 1997
- *Demonstration of the Aventech Aircraft-Mounted Meteorological Measurement System*, May 1997
- *GPS Walk Method of Determining Area*, May 1997
- *Wide Area GPS Enhancement (WAGE) Evaluation*, August 1997
- Practical Application of G.P.S. Technology: Differential GPS Spray Aircraft Guidance, March 1998
- Resource Applications of GPS Technology, August 1998
- Evaluation of the Trimble ProXRS GPS Receiver Using Satellite Real-Time DGPS Corrections, May 1999

Copies of the most current of these documents can be ordered from MTDC. Electronic copies of some of the documents are available to Forest Service employees on the Forest Service's internal computer network at the FSWeb address: http://fsweb.mtdc.wo.fs.fed.us.

MTDC and GPS

In August of 1983 the Forest Service's Washington Office Division of Engineering assigned MTDC a project to investigate GPS technology. Engineering and Timber staff groups were the first sponsors of this program. They recognized the potential of GPS technology for resource management activities. The program is currently sponsored by Forest Service staff groups responsible for engineering, timber management, fire and aviation management, forest health protection, recreation, law enforcement, research, lands and mineral management, and wildlife.

Before the advent of GPS, MTDC examined other radio-navigation systems such as Loran, local radio-beacon matrix, and microwave. Loran-C was investigated as a possible spray-aircraft guidance system for Forest Health Protection. Its coverage area was too limited and it was not accurate enough. Other technologies using local networks tended to be exorbitantly expensive, because they needed to be configured and constructed for each project site.

GPS had a proposed accuracy of 16 meters (3-D) spherical-error probability (SEP) and 8 meters (2-D) circular-error probability (CEP), with 24 hour-a-day availability and worldwide coverage. The role of MTDC has been to evaluate whether this new technology could be applied to Forest Service operations. Responses to a Servicewide questionnaire in 1984 identified 140 possible resource applications. These varied from locating oil well heads, to guiding spray aircraft and marking wildlife nesting trees.

A workshop was held by the Center in May 1986 for GPS manufacturers, Forest Service users, and representatives from the Department of Defense's GPS Joint Program Office (JPO). Nine manufacturers participated, as did 25 Forest Service personnel representing most resource functions. This meeting produced an exchange of ideas between manufacturers and field users that gave the GPS industry a better understanding of Forest Service requirements and needs.

In July 1986, Rockwell Collins demonstrated its NAVCORE I receiver at MTDC. This system weighed 10 pounds without batteries and had to be carried in a backpack. The battery pack added another 10 pounds and only provided for 3 hours of operation. Even with these limitations, the system was impressive when it was evaluated a year later by MTDC on the University of Montana's Lubrecht Experimental Forest near Missoula, Montana. Field personnel especially liked its ability to digitize road locations for mapping. The forest canopy's tendency to attenuate the signal and degrade horizontal accuracy was noted during these early tests. MTDC issued a report and overall evaluation of the system.

The NAVCORE I evaluation pointed up the need for a test and training facility. In June 1987 a memorandum of understanding with the University of Montana School of Forestry was signed establishing such a facility at the Lubrecht Experimental Forest (Figure 4).

That same year MTDC contracted with GPO Hydro, Inc., to bring geodetic control (1-250,000) to the site. The test site represented a forest canopy typical of the Northwest. From this control survey several closed traverses were surveyed with known coordinates determined for each station (Figure 5). These known coordinates were used to evaluate the accuracy of GPS systems being tested at the site. The test site would also help instructors teach students GPS procedures and methods.

After the 1986 manufacturer-user workshop, Trimble Navigation asked MTDC to evaluate its prototype TANS GPS receiver. This was a 2-channel portable unit weighing 10 pounds with batteries. This unit's accuracy was 8 meters, with the possibility of differential correction down to 2 to 5 meters. This level of accuracy was considered excellent at this time. Selective Availability (SA) had not yet been turned on. MTDC eventually acquired a Trimble TANS receiver, the Center's first GPS system.

In June 1988 the first of 26 GPS training sessions was conducted at Lubrecht

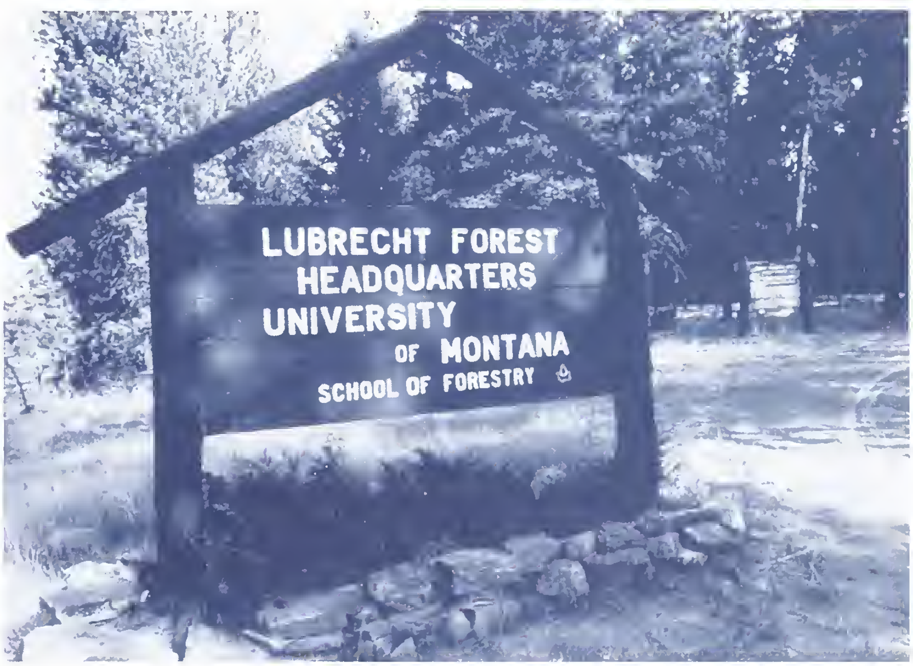


Figure 4—In 1987 a cooperative agreement was signed with the University of Montana establishing a GPS test and training facility at the University's Lubrecht Experimental Forest.

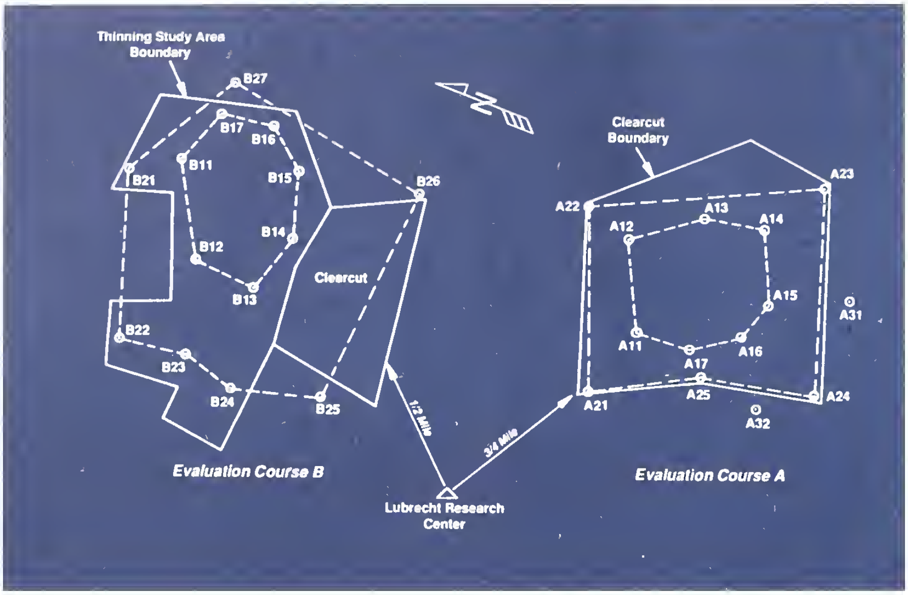


Figure 5—A control survey established several closed traverses with known coordinates at the Lubrecht test site.

under the auspices of the University and the Center. These 3-day sessions included about 15 to 20 students, and were scheduled four times a year (Figure 6). They provided realistic hands-on training in a typical resource-management environment. GPS manufacturers were invited to attend and demonstrate their products to the students. This interaction led GPS manufacturers to develop lighter receivers tailored to Forest Service

Figure 6—In June 1988 the first of 26 GPS training sessions was conducted at Lubrecht under the auspices of the University of Montana and MTDC.

needs that were capable of better accuracy under forest canopies. These classes also helped expose many Forest Service personnel to the possibilities of GPS technology.

MTDC prepared the specifications for a contract for 50 TANS receivers that was let in June of 1989. MTDC subsequently asked that this Trimble receiver be made available through the General Services Administration (GSA). GPS technology was rapidly becoming more sophisticated at this time. A 6-channel receiver was evaluated by MTDC. It had improved efficiency under a dense canopy. The Center prepared specifications for this advanced system. Trimble again won the bid. By October 1992, Trimble had supplied over 500 6-channel units. By 1993 many GPS manufacturers had arranged to have their equipment available through GSA.

In July 1989 a GPS Steering Committee was formed to guide implementation of GPS technology in the Forest Service. The committee developed a Servicewide plan that directed the Center to provide direction in GPS training and procurement, establish test and evaluation sites, and test equipment to ensure that field users had the best possible GPS equipment.

Three additional GPS test sites were located and surveyed. In April 1991, an eastern site was established under a heavy canopy of mixed oak, hickory, and beech on the Hoosier National Forest near Bedford, Indiana. A West Coast site was set up in 1995 on the Clackamas District of the Mount Hood National Forest. This site is in a stand of dense, second-growth Douglas-fir and western hemlock. In 1998, a northeastern hardwood site was established at Ridley Creek State Park, Pennsylvania. In 2000 another site will be operational under an old-growth cedar canopy on the Montana-Idaho border. These sites allow MTDC to evaluate GPS equipment under canopy conditions representative of those that Forest Service users could expect to encounter.

In May 1994, the Forest Service and several other civilian agencies were authorized to acquire and operate the military Precise Positioning Service (PPS) receivers through a memorandum of agreement signed with the Department of Defense. These receivers provide resource managers with a GPS unit capable of an autonomous accuracy of 9 to 10 meters under a dense forest canopy. PPS receivers require that their security modules be keyed each year. MTDC established a Communications Security Account (COMSEC) with the National Security Agency. This account allows the Center to acquire the classified keying materials. Today over 500 PPS receivers are in use throughout the Forest Service. All receivers are rekeyed annually and serviced by the COMSEC facility at MTDC.

Figure 7—The GPS Support Program has evaluated data loggers capable of downloading data into Arc/Info and other GIS software.

Operational GPS Support

MTDC has supported GPS throughout the Forest Service by working with the electronics industry to obtain equipment that is more suitable for Forest Service operations. The Center's GPS program personnel are active members of all GPS user committees within the Forest Service and represent the Forest Service at GPS meetings sponsored by the DOD and civilian governmental agencies. The Center lobbied DOD in 1997 for a relaxation of user restrictions for PPS P(Y) code receivers. This relief was granted, allowing GPS technology to be used in Forest Inventory and Analysis (FIA) operations.

The GPS Support Program has evaluated data loggers (Figure 7) and pen-plotter equipment capable of downloading data into Arc/Info and other GIS software. The program worked with law enforcement in the early 1990's on a method of tracking log rafts in the Gulf of Alaska using the ARGOS satellite system. The Center has evaluated Wide Area GPS Enhancement (WAGE) and conducted a number of user surveys to determine the types of GPS equipment that is needed in the field.

Experience with GPS receivers has shown that topography and vegetation (such as a tree canopy) may block or attenuate satellite signals. The signal can be fairly strong where no foliage interferes, but be completely blocked only a few meters away (Figure 8). Signals that bounce off nearby cliffs before reaching a GPS receiver (multipath signals) create positional errors. Even when the receiver is stationary, the amount of foliage in the signal path can change rapidly due to wind in the canopy. Movement of the receiver and of the satellites in and near canopies or in

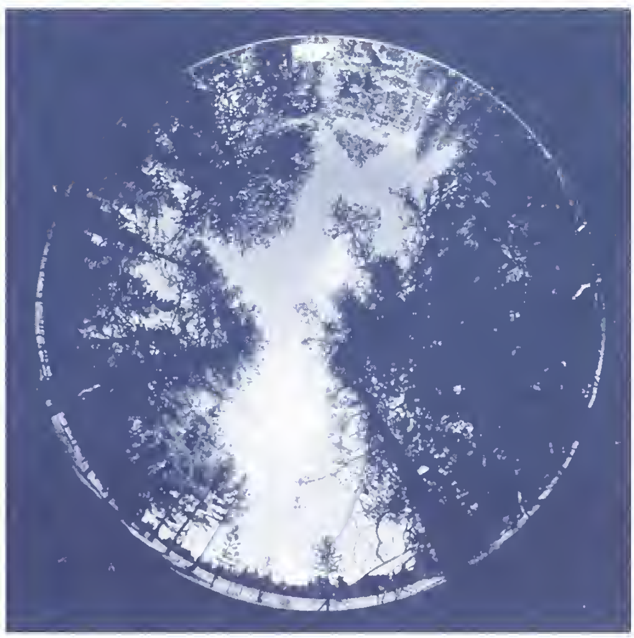


Figure 8—Early tests at Lubrecht showed the effect a tree canopy had on GPS receiver performance and how horizontal accuracy was degraded.

complex terrain affect the signal due to the spatial variability of these obstructions. As the signal gets weaker, the receiver has a harder time tracking it and begins to lose the signal in the background noise, degrading accuracy. The efficiency and accuracy of a GPS receiver under heavy canopy depends on its signal-tracking ability. The more capable receivers are more expensive. Rapid technological advancements in signal-tracking circuitry and signal processing have improved the efficiency of GPS systems in the past few years. Even so, some GPS receivers do not work well under a dense forest canopy.

Forest Service personnel need to know the capabilities of available equipment before buying expensive GPS systems. They need verification of manufacturer's claims, and reasonable assurance that the equipment will perform in their work environment. The GPS test sites established across the United States allow MTDC to evaluate GPS equipment and procedures under the most adverse conditions Forest Service personnel may encounter. Results of these evaluations are distributed throughout the Forest Service in MTDC's Tech Tips. The Center has published 20 Tech Tips and other reports on GPS equipment since 1986.

International Forestry and GPS

In 1993 the U.S. Agency for International Development (USAID) and the Forest Service's International Forestry Program asked MTDC to develop and provide a GPS training program for natural-resource managers in Indonesia and later in the Philippines.

The GPS training was designed to meet the needs of both natural-resource managers and field workers. The course emphasized the basics of GPS, operation of GPS receivers under field conditions typical of resource-management tasks, and operation of the postprocessing software for data reduction.

From 1993 to 1995 eight training sessions were conducted in Indonesia, four for Indonesia Ministry of Forestry personnel (Figure 9) at a site near Bogor, and four for USAID personnel in Manado and Pontianok. These sessions trained about 120 personnel on GPS operations. Three employees of the Indonesia Ministry of Forestry came to Missoula, Montana, for training. One training session was conducted for the National Resources Management Program in the Philippines.

Figure 9—In 1993 the U.S. Agency for International Development (USAID) asked MTDC to develop and provide GPS training for natural-resource managers in Indonesia.

The Philippine training was conducted at a site on the old U.S. Naval Base at Subic Bay. MTDC personnel spent 3 days setting up a temporary base station, laying out a course, and collecting data for the field portion of the instruction. The 23 students who attended this session were from organizations such as the Department of Environment, the Forestry Support Organization, and regional governments. The majority were involved in boundary work dealing with delineation of ancestral lands and illegal logging. No geodetic control existed in any of these areas.

Differential GPS and Aerial Spray Operations

The rapidly evolving technology of Differential GPS-based (DGPS) navigation has had a great impact on agricultural and forestry aerial spray operations. Applying insecticides, herbicides, and fertilizers accurately, safely, and efficiently depends on a pilot's ability to identify spray plot boundaries and to correctly position the aircraft for subsequent spray swaths. Good block marking and aircraft positioning are necessary to reduce the risk of applying spray materials to sensitive nontarget areas such as watercourses, and to ensure uniform application to the intended plot.

Let us first of all try to understand the difficulties of aerial navigation as faced by the ordinary balloonist. One of the principal problems is the difficulty of ascertaining the direction during the night or when above the clouds. It is hard, perhaps, for the person who has never been in a balloon or a flying-machine to understand this. In day-time, and when the earth is in sight, it is quite a simple matter, with the aid of the compass, to take the line of the balloon's course. At night, if no fixed lights on the earth be visible, or if the balloon be over the sea, it is impossible. The compass-needle points to the north, but the aeronaut has no means of ascertaining the direction the balloon is taking. And it is equally impossible in daylight when above the clouds, for the clouds may be moving in the same direction as the balloon, or in some totally different direction. Only if one could be quite sure that they were stationary would it be possible to ascertain the direction.

from *Aerial Navigation of Today*,
Clark C. Turner
Seeley and Co. Limited,
London, 1910.

In flatland agricultural spraying, flagmen and ground markers were commonly used to mark blocks. In a forest setting these methods are difficult to use. Alternative marking techniques included tethered balloons, crepe paper streamers dropped from aircraft, and paint sprayed on treetops from helicopters. These methods were labor intensive and sometimes dangerous or ineffective. DGPS almost eliminates the spray block-marking problem. In addition, DGPS provides for more uniform application of spray product throughout the block. DGPS aerial application systems can record the spray aircraft's path, exact flow rate, and whether the product is being applied or not. They can also report other variables of interest to an aerial applicator. These data enable the spray pilot and the Forest Service operational manager on the scene to determine whether the spray block has received full coverage. The spray coverage as recorded by the DGPS system in a computer file is available for GIS archiving or subsequent analysis.

When the Forest Service began using GPS guidance in spray operations during 1993 and 1994, problems arose with the systems themselves, with the training level of the operators, and with system integration. Though DGPS had been used in aerial pesticide application over uniform terrain since the early 1990's, the technology was changing rapidly and many of the systems supplied by the manufacturers to Forest Service spray projects were prototypes. In some cases, operating manuals were not available to pilots. Inexperience with the systems and their methodology for file storage resulted in the loss of spray data. In some systems logged data was difficult to convert into a GIS format. These problems prompted the Forest Health Protection (formerly Forest Pest Management) staff and MTDC to schedule a series of demonstrations and evaluations of DGPS aerial spray systems.

The evaluations were designed to acquaint Forest Service personnel with system capabilities and to acquaint equipment manufacturers with the unique requirements of aerial spraying in forested, complex terrain (Figure 10).

MTDC scheduled the first demonstration for the week of October 9, 1994, and canvassed the GPS aircraft-navigation industry for potential demonstrators. Two firms agreed to participate. About 75 personnel from Federal and State agencies in the United States, and from Canada, New Zealand, and Australia attended this demonstration. Two afternoons of technical discussions addressed many of the startup problems associated with the new DGPS systems.

Subsequent demonstrations involved both fixed-wing and helicopter operations and investigated the accuracy claims made by the manufacturers and problems associated with system update rates. Pilots complained of slow position updating after a turn. Spray project managers had problems with "castling" on plot edges. The advantages and disadvantages of automated spray on-off features were examined. Problems associated with integrating the DGPS archival information with GIS were worked out and a pest-management software package developed by the Forest Service (GYPSES) was successfully integrated with an aircraft DGPS system.

These demonstrations were well attended by Forest Service and State personnel. Many leading aerial application DGPS equipment manufacturers participated. The dialog between pilots, operational personnel, and electronic-systems manufacturers facilitated widespread acceptance of this technology (Figure 11). Forest Service personnel were better able to write viable spray contracts, and manufacturers learned the unique requirements of forest spray operations. The ability of Forest Service managers to take full advantage of DGPS guidance in aerial spray operations over complex terrain is due in large part to these demonstrations and evaluations.

Aircraft-mounted meteorological measuring equipment has also been

Figure 10—Forest Service operations over complex terrain posed unique problems for GPS guidance equipment originally designed for applications on flat agricultural land.

Figure 11—The dialog between pilots, operational personnel, and electronic systems manufacturers at MTDC demonstrations helped GPS guidance systems become accepted in Forest Service operations.

investigated by MTDC. This equipment has potential applications in aerial spraying and in wildland firefighting operations. A Canadian system using a device mounted on a light aircraft (Figure 12) was evaluated by the Center in 1997. This system transmitted the flight altitude profile, temperature, dew point, wind speed, and wind direction to a PC screen on the ground while simultaneously plotting the aircraft's position on an overlay map. Current work includes integrating aerial spray dispersion and deposition modeling with DGPS guidance systems so that the aerial applicator has an idea of the coverage rate during application and has an idea how much material is moving off-target. Aircraft positional information needs to be integrated with weather data, system mechanical information such as droplet size and flow rate, and a GIS system to provide real-time guidance to the applicator.

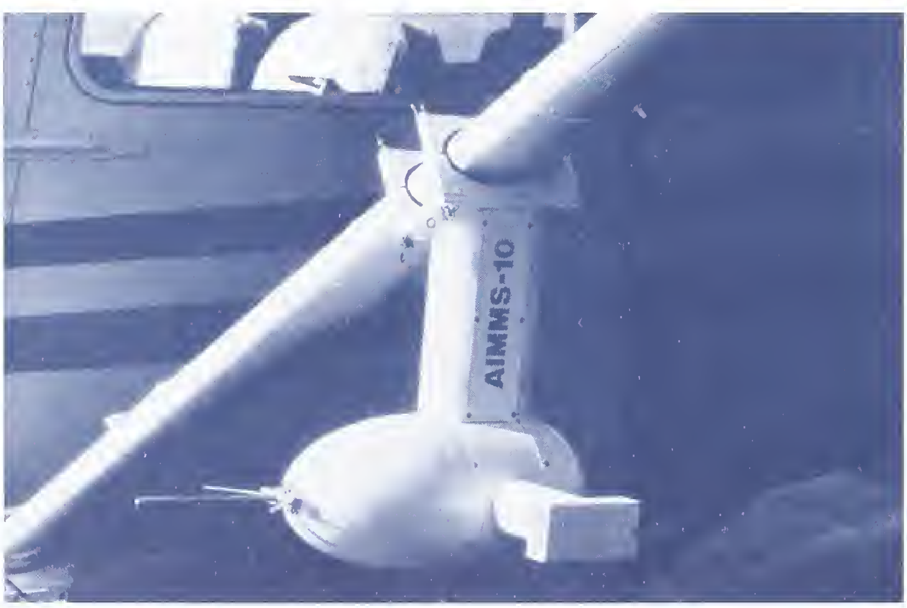


Figure 12—An aircraft-mounted meteorological sensor package was evaluated by the Center in 1997. Sensors transmitted the temperature, dew point, wind speed, and direction to a ground-based PC while simultaneously plotting the aircraft's position on an overlay map.

PPS P(Y) Code Receiver Support

Under the guidance of the National Security Agency (NSA), MTDC established a Communications Security account and rekeying facility at Missoula, Montana, in 1995.

The COMSEC account custodian oversees the security of P(Y) code receivers and works with Air Force Space Command at Peterson Air Force Base in Colorado Springs and with the National Security Agency at Fort Meade, Maryland, to ensure that Forest Service organizations are aware of the security issues involved with these devices. The custodian secures permission from the National Security Agency for Forest Service personnel to travel overseas with P(Y) code receivers, and coordinates with the Defense Courier Service when receiving new DOD key codes.

Each PPS receiver contains a code module that must receive a "key" to be activated. This key is changed on a date that is kept secret by DOD. Without this key, the receivers can not access the Y code.

All Forest Service PPS P(Y) code receivers must be rekeyed at least once a year at the Missoula COMSEC facility. In addition, about one-fourth of the receivers are keyed more than once a year because of battery failure or inadvertent cancellation of the key.

Conclusions

GPS technology has facilitated substantial advances in resource management over the last decade. The ability to inventory natural resources over large, remote areas has been dramatically improved. The ability to arrive or return to an exact location on the ground in a remote setting has improved by over two orders of magnitude in some cases. These abilities have benefited scientific investigation, search and rescue, fire spotting, forest pest outbreak evaluation, and many other areas of Forest Service endeavor. Navigational abilities, whether on foot, by ground vehicle, or by air, have been revolutionized. Resource managers have been given the ability to electronically archive a positional history, whether it be of a flightline or spray plot in aerial spraying, or of a new trail or campground for a recreational manager.

Perhaps the most profound impact of this technology for the Forest Service is that it allows remote forest lands to be accessed and enjoyed with an added degree of safety and security by a wider segment of the public.

Applications and ideas based on this technology are still emerging and continue to be evaluated by the Missoula Technology and Development Center.

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